

# 2

## Plate Tectonics ...and Your Community

### Getting Started

Plate tectonics is a scientific theory. A scientific theory is a well-tested concept that is supported by experimental or observational evidence. It explains a wide range of observations. The theory of plate tectonics explains the formation, movement, and changes of the outer, rigid layer of the Earth, called the lithosphere.

- How do you think the Earth's lithosphere formed?
- How do you know that the Earth's lithosphere moves?
- List some ways that the Earth's lithosphere changes.

What do you think? Write down your ideas about these questions in your notebook. Be prepared to discuss your ideas with your small group and the class.



## Scenario

A middle-school science teacher in your community has been asked to teach a unit on plate tectonics to her class and has asked for your help. To her students, the fact that they are riding on Earth on a floating plate makes about as much sense as riding on a magic carpet. The students feel that because plate tectonics is “just a theory” that scientists have “made up,” there is no need for them to learn about it, or try to understand it. Also, they believe it is totally irrelevant to their lives.

The teacher hopes that her students might be more likely to listen to local high school students. She would like you to convince her class of the significance of plate tectonics in their lives. She wants you to explain to her class the key science concepts behind the theory. She thinks that it would help her students if they could see how research, evidence, modeling, and technology support plate tectonics.

Can the EarthComm students meet this challenge and help a middle-school class to understand why the theory of plate tectonics is important to learn about and understand?

## Chapter Challenge

Think about how you can use the theory of plate tectonics to help middle-school students understand scientific theories. You might want to prepare a PowerPoint™ presentation, a web page, or a three-panel poster display. Your project will need to address:

- Evidence for movement and changes in the geosphere over time.
- The flow of matter and energy in the Earth.
- The nature of the Earth’s interior.
- How plate tectonics accounts for the features and processes that geoscientists observe in the Earth.
- How the theory of plate tectonics developed.

## Assessment Criteria

Think about what you have been asked to do. Scan ahead through the chapter activities to see how they might help you meet your challenge. Work with your classmates and your teachers to define the criteria for judging your work. Record all this information. Make sure that you understand the criteria as well as you can before you begin. Your teacher may provide you with a sample rubric to help you get started.





## Activity 1

# Taking a Ride on a Lithospheric Plate



### Goals

In this activity you will:

- Determine the direction and rate of movement of positions within the plate on which your community is located, using data from the Global Positioning System and a computer model.
- Predict the position of your community in the near future, and "retrodict" its position in the recent past, by extrapolating from data already collected.
- Recognize that the rate and direction of plate motion is not necessarily constant.
- Describe several lines of evidence for plate motion.

### Think about It

The motion of anything (you, your automobile, a lithospheric plate, or the Milky Way Galaxy!) has to be described in relation to something else.

- How can you locate your position on the Earth's surface?
- How would you be able to determine whether your position on the Earth has moved?

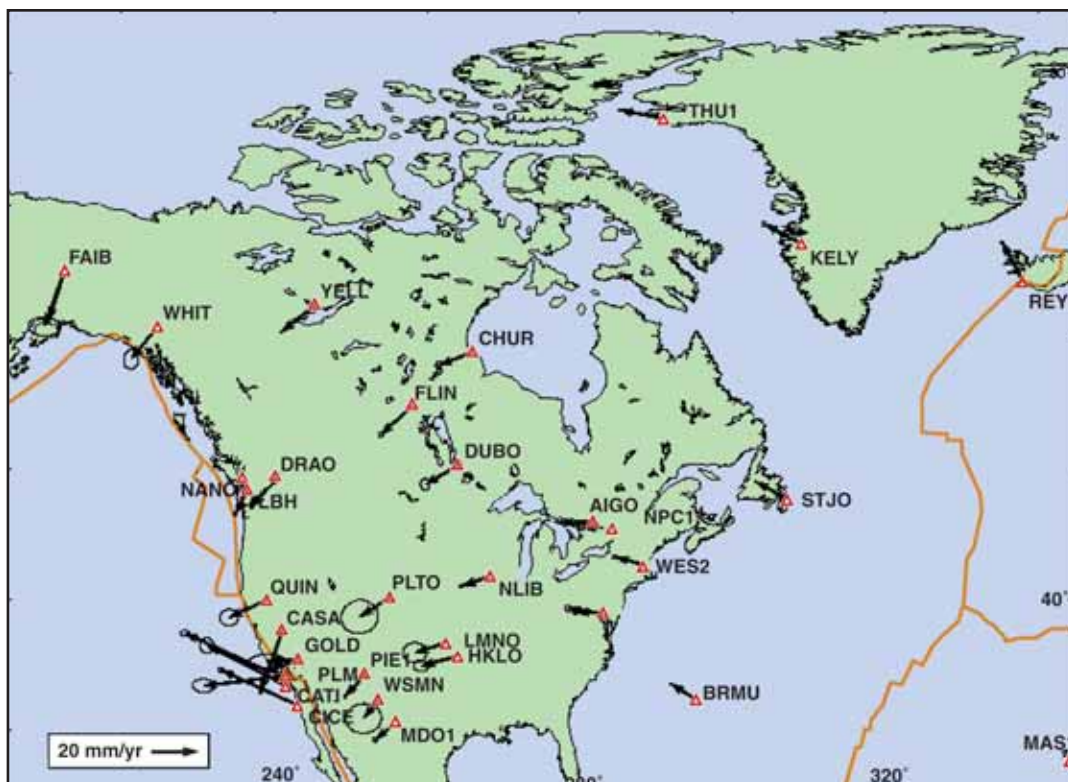
What do you think? Record your ideas about these questions in your *EarthComm* notebook. Include sketches as necessary. Be prepared to discuss your responses with your small group and the class.

## Investigate

### Part A: Data from the Global Positioning System

1. Data from Global Positioning System (GPS) satellites will help you find out if the position of your community has changed over time. The map shows measurements of movements at GPS recording stations in North America. Each station has a four-character

symbol. Arrows show the rate and direction of motion of the Earth's surface at that station. Longer arrows indicate faster motion than shorter arrows. The motions shown are relative to the GPS frame of reference, which you can think of as "attached" to the Earth's axis of rotation.



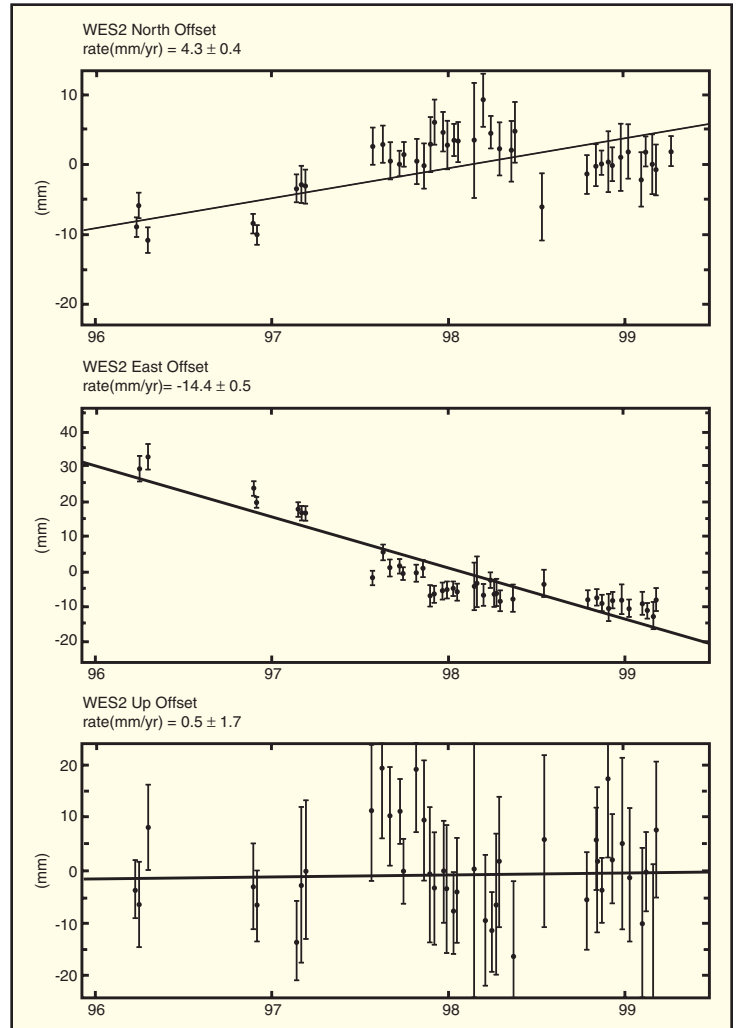
Measurements of movements at GPS recording stations in North America.

- a) Find the WES2 station (in the northeastern United States). How do you know that the WES2 station has moved over time?
- b) In what compass direction is the WES2 station moving? Be specific.





- c) The arrow in the lower left corner of the map is a scale. It shows the length of a “20 mm/yr” arrow. Is the WES2 station moving more than or less than 20 mm/yr? Explain.
  - d) Are all stations on the map moving at the same speed? Explain.
  - e) Are all stations on the map moving in the same direction? Explain.
  - f) What is the general or average direction of movement of North America?
2. A series of measurements of the location and elevation of a GPS station over time is called a GPS time series. The graph shows the GPS time series for the WES2 station. The solid sloping lines on the three graphs are the “best-fit” lines through the data points.  
Use the map and the time series to answer the following questions:
    - a) How many years of data does the time series show?
    - b) Were measurements recorded continuously or only at certain times? Explain your answer.
  3. The top graph shows movement of the station to the north or south. Northward movement is indicated by positive values, and southward movement is shown by negative values. Find the calculation above the top graph. How many millimeters per year did WES2 move? Convert



The location and elevation of GPS station WES2 over time. The vertical lines above and below each point are called “error bars”. They show the uncertainty in the measurement. They tell you that the real value might lie anywhere within the error bar.

this value to centimeters per year. In which direction did it move?

- a) Record the rate (in cm/yr) and the direction of motion in your notebook.

4. The middle graph shows movement to the east or west. Eastward movement is indicated by positive values, and westward movement is shown by negative values. Find the calculation above the middle graph. How many millimeters per year did WES2 move? Convert this value to centimeters per year. In which direction did it move?
  - a) Record the rate (in cm/yr) and direction of motion in your notebook.
5. The bottom graph shows the movement up or down.
  - a) Has the WES2 station always stayed at the same elevation? Explain.
6. Do the speed and direction of motion of WES2 shown in the graphs match the direction and length of the arrow shown on the map?
7. Look at the “best-fit” line in the top and middle graphs.
  - a) Did the WES2 station move at a constant speed since 1996? Explain your answer.
  - b) What additional data would you need to decide whether the differences between the measured data points and the best-fit straight line are due to the overall motion of the plate or are caused by processes in the local area around the WES2 station?
8. Obtain a GPS time series for a station nearest your community.
  - a) Record the directions and rates of motion in cm/yr for the station nearest your community.

### Part B. Data from a Computer Model

1. Computer models that use geologic data also provide information about the changes in position of your community over time. To use this model, you will need to know the latitude and longitude of your school in decimal format.

Find your school (or another familiar place) on your local topographic map. Latitude and longitude are used to identify a position on the Earth's surface. Latitude is a measure of location in degrees, minutes, and seconds north or south of the equator. Therefore, it is found on the left or right side of the map. Longitude is a measure of location in degrees, minutes, and seconds east or west of the Prime Meridian, which passes through Greenwich, England. Therefore, it is found on the top or bottom of the map.

- a) Record the latitude and longitude of the position you chose in degrees, minutes, and seconds. (These “minutes” and “seconds” are *not* the same as the familiar minutes and seconds of time! They describe positions on a circular arc.)
- b) Convert the latitude and longitude values to a decimal format. An example for you to follow is provided on the following page.



*Example:*

42° (degrees) 40' (minutes) 30" (seconds) north latitude  
Each minute has 60".  
30" divided by 60" equals 0.5'.  
This gives a latitude of 42° 40.5' north.  
Each degree has 60'.  
40.5' divided by 60' equals 0.675°.  
The latitude in decimal format is 42.675° north.

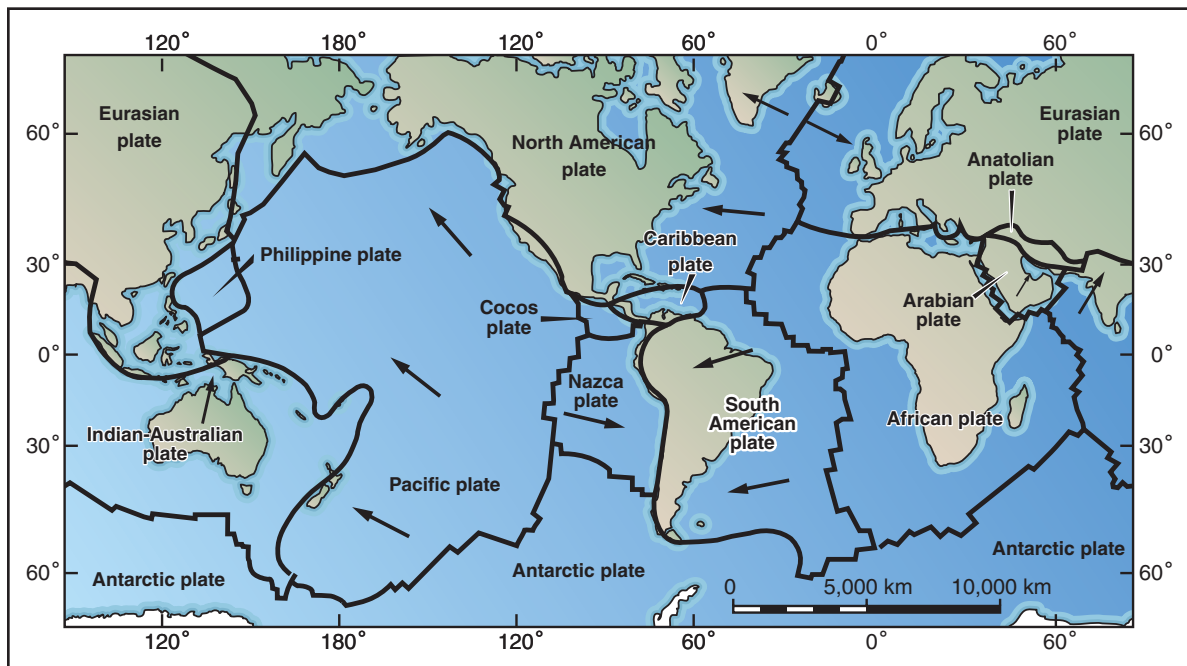
2. Obtain a world outline map showing lithospheric plates, similar to the one shown.

a) Place a dot on the map to represent the location of your community and label it with an abbreviation.

b) In your notebook, record the name of the plate your community lies within. Record the name of a plate next to your community.

3. Visit the Relative Plate Motion (RPM) Calculator web site. (See the *EarthComm* web site for more information.) The RPM calculator determines how fast your plate is moving relative to another plate that is assumed to be "fixed" (non-moving). At the web site, enter the following information:

- The latitude and longitude of your community (decimal format).
- The name of the plate on which your community is located.
- The name of the "fixed" reference plate adjacent to your plate. Use the African Plate as the reference plate.



World map of major lithospheric plates. Arrows show the relative motions of the plates relative to the African Plate, which happens to be moving slowest relative to the Earth's axis of rotation.

Once you have entered the data, run the model. Print the results. (A sample printout for the location of station WES2 is provided for you.) Record the following information in your notebook:

- a) The rate of movement of the plate on which your community is located (in centimeters per year).
- b) Its direction of motion. (Note that direction is given in degrees, starting from  $0^\circ$ , clockwise from north. For example,  $90^\circ$  is directly east,  $180^\circ$  is directly south and  $270^\circ$  is directly west.)
- c) In your own words, describe the motion of your plate over time.
- d) How do the results from the computer model compare to those obtained from GPS data?
- e) What data does GPS provide that the plate motion calculator does not?

**NUVEL-1A Calculation Results**  
Calculation results are as follows:

Relatively fixed plate = Africa  
 Relatively moving plate = North America  
 Latitude of Euler pole =  $78.8^\circ$   
 Longitude of Euler pole =  $38.3^\circ$   
 Angular velocity =  $0.24^\circ/\text{million years}$   
 Latitude inputted =  $42.364799^\circ$   
 Longitude inputted =  $-71.293503^\circ$   
 Velocity = 2.11 cm  
 Direction =  $283.39^\circ$

## Reflecting on the Activity and the Challenge

So far, you have learned that when you use GPS data collected over time, you can find the speed and direction of movement of your plate. You can also use data from a computer model to show that your community is moving as part of the movement of a large plate. You are riding on a piece of the Earth's lithosphere! Your maps show how your community, along with the plate on which it rides, has moved over time. You can also predict its future position. You have now gathered some evidence to help you explain to the middle school students that their community is in fact moving.







### Geo Words

**crust:** the thin outermost layer of the Earth. Continental crust is relatively thick and mostly very old. Oceanic crust is relatively thin, and is always geologically very young.

**mantle:** the zone of the Earth below the crust and above the core. It is divided into the upper mantle and lower mantle with a transition zone between.

**lithosphere:** the outermost layer of the Earth, consisting of the Earth's crust and part of the upper mantle. The lithosphere behaves as a rigid layer, in contrast to the underlying asthenosphere.

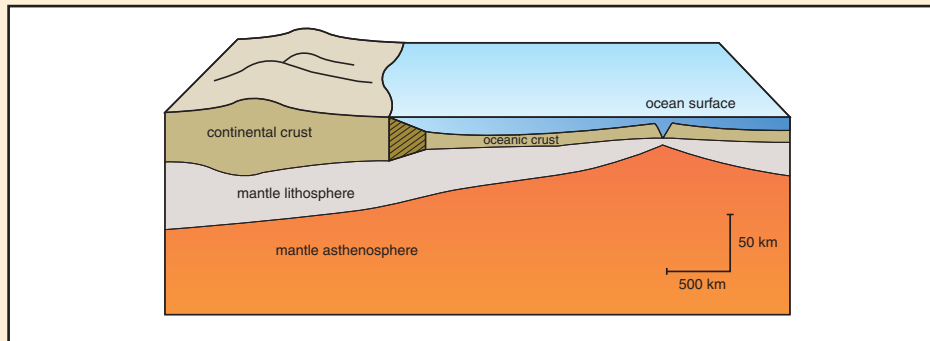
**asthenosphere:** the part of the mantle beneath the lithosphere. The asthenosphere undergoes slow flow, rather than behaving as a rigid block, like the overlying lithosphere.

## Digging Deeper

### MEASURING THE MOTION OF LITHOSPHERIC PLATES

#### The Interior Structure of the Earth

Refer to *Figure 1* as you read this section. The thin, outermost layer of the Earth is called the **crust**. There are two kinds of crust: continental and oceanic. The continental crust forms the Earth's continents. It is generally 30–50 km thick, and most of it is very old. Some continental crust has been dated as old as four billion years! The geological structure of the continental crust is generally very complicated, as you will learn in a later chapter. In contrast, the oceanic crust is only 5–10 km thick, and it is young in terms of geologic time. All of the oceanic crust on the Earth is younger than about 200 million years.



**Figure 1** A schematic cross section through the outer part of the Earth. Note that the vertical and horizontal scales are very different. The diagram has a lot of “vertical exaggeration”. If the diagram had been drawn without distortion, all of the layers would look much thinner. The boundary between continental crust and oceanic crust, shown by the shaded box, will be described later in the chapter.

Beneath the Earth's crust is the **mantle**. The rocks of the mantle are very different in composition from the crust, and the boundary between the crust and the mantle is sharp and well defined. The uppermost part of the mantle, which is cooler than below, moves as a rigid block, carrying the crust with it. The upper rigid part of the mantle, together with the crust, is called the **lithosphere**. The Earth's plates are composed of the lithosphere. At greater depths, the mantle is hot enough that it can flow very slowly, just like a very stiff liquid. That part of the mantle is called the **asthenosphere**.

In terms of composition and origin, the crust and the mantle are very different, but in terms of how they move, they behave in the same way. On the other hand, the lithosphere part of the mantle is the same in composition as the asthenosphere part of the mantle, but in terms of how they move, they behave very differently.

### Measuring Plate Motions with GPS

The **Global Positioning System (GPS)** consists of 24 satellites that orbit the Earth at a height of 20,200 km. Receivers at stations on Earth (such as WES2 in Westport, Massachusetts) use the signals from satellites to calculate the location of the station. Geoscientists have set up a network of targets all over the world in order to monitor the movement of lithospheric plates. Steel spikes pounded into the ground (preferably embedded in solid rock) make up the targets, as shown in *Figure 2*. A high-precision GPS receiver is then mounted on a tripod and positioned directly above the target. The targets are revisited over a period of months or years. The receiver measures the distance to four or more GPS satellites and then uses stored data on satellite locations to compute the location of the target. Changes in horizontal and vertical positions can be detected within several millimeters.



**Figure 2** A GPS receiver mounted in rock is used to measure changes in the elevation of this volcano.

GPS data collected at stations all over the world confirm that the surface of the Earth is moving. However, GPS time series show data for only the last several years. GPS is a new technology, and a global network of GPS stations has existed for less than a decade. How do we know that the surface of the Earth has been moving for a longer period of time? The answer to this question comes from the study of rocks.

### Sea-Floor Spreading

The computer model at the Plate Motion Calculator web site uses several sources of geologic data. One source comes from the study of the magnetism of rocks that make up the sea floor. All magnets and



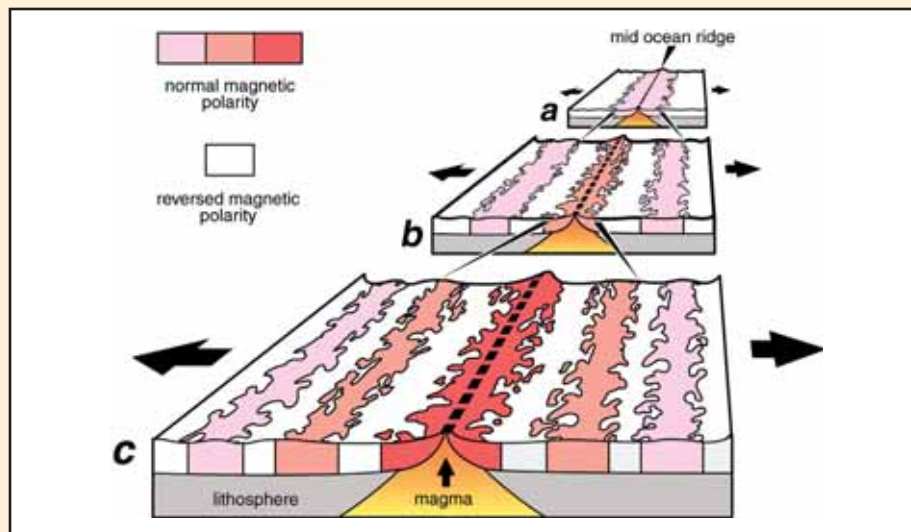
### Geo Words

**Global Positioning System (GPS):** a satellite-based system for accurate location of points on the Earth.



materials that have magnetism have a north and south direction, or magnetic polarity. In the middle of the 20th century, geoscientists noted that they could group rocks by their magnetic polarity. Rocks with normal magnetic polarity match that of the Earth's magnetic field (the north end of the rock's "compass needle" points toward magnetic north.) The other group has magnetic minerals with reversed polarity (the north end of the rock's compass needle points south).

It was known that as lava cools to form **basalt** (an iron-rich volcanic rock that makes up the ocean floor), its iron minerals (such as magnetite) become magnetized and "lock in" the polarity of the Earth's magnetic field. Beginning in the 1950's, scientists began noting patterns in the magnetism of rocks on the ocean floor, as shown in *Figure 3*. The alternating belts of higher and lower than average magnetic field strength were of normal and reverse polarity, respectively.



**Figure 3** The formation of magnetic striping. New oceanic crust forms continuously at the crest of the mid-ocean ridge. It cools and becomes increasingly older as it moves away from the ridge crest with sea-floor spreading: a. the spreading ridge about 5 million years ago; b. about 2 to 3 million years ago; and c. present day.

In 1963, two scientists, F.J. Vine and D. H. Matthews, proposed the revolutionary theory of sea-floor spreading to explain this pattern. According to their theory, the matching patterns on either side of the **mid-ocean ridge** could be explained by new ocean crust forming at the ridge and spreading away from it. As ocean crust forms, it obtains the polarity of the Earth's magnetic field at that time. Over time, the strength of the Earth's

magnetic field changes. When new ocean crust forms at the center of the spreading, it obtains a new kind of magnetic polarity. Over time, a series of magnetic “stripes” are formed.

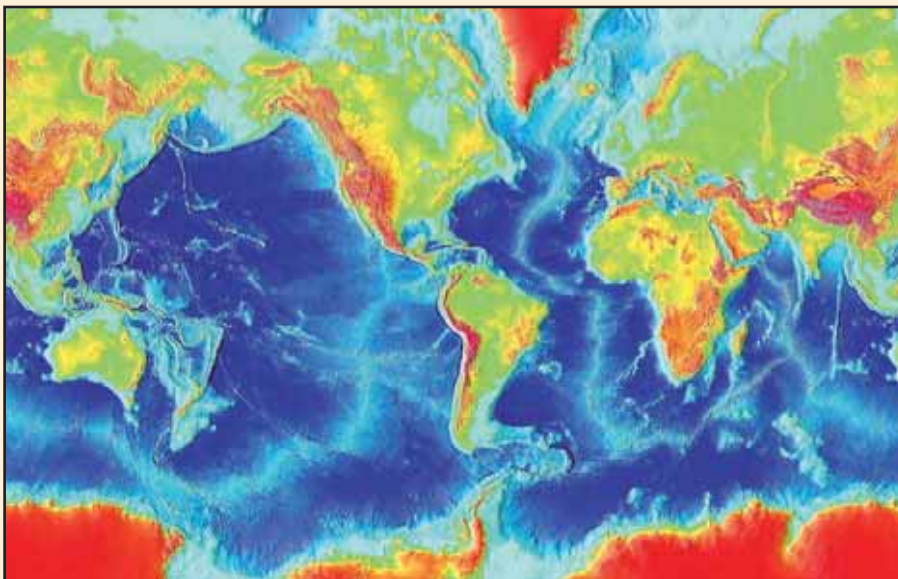
Since the theory of sea-floor spreading was proposed, core samples of volcanic rock taken from the ocean floor have shown that the age of the rock increases from the crest of the ridge, just as the theory predicts. What's more, by measuring both the age and magnetic polarity of rocks on land, geologists have developed a time scale that shows when the magnetic field has reversed its polarity. Because the magnetic striping on the ocean floor records the reversals of the Earth's magnetic field, geoscientists can calculate the average rate of plate movement during a given time span. These rates range widely. The Arctic Ridge has the slowest rate (less than 2.5 cm/yr), and the East Pacific Ridge has the fastest rate (more than 15 cm/yr). The computer model in the plate motion calculator uses spreading rates from ocean ridges throughout the world to compute plate motion.

Geologic data is also used to find the direction of movement of the plate. Surveys of the depth of the ocean floor, mainly since the 1950s, revealed a great mountain range on the ocean floor that encircles the Earth, as shown in Figure 4. This mid-ocean ridge zig-zags between the continents, winding its way around the globe like the seams on a baseball. The mid-ocean ridge is

### Geo Words

**basalt:** a kind of volcanic igneous rock, usually dark colored, with a high content of iron.

**mid-ocean ridge:** a chain of undersea ridges extending throughout all of the Earth's ocean basins, and formed by sea-floor spreading.



**Figure 4** Map of the world ocean floor. The crest of the mid-ocean ridge system is shown as a broad light blue line throughout the ocean floor. The flanks of the mid-ocean ridges slope gradually down to the deeper part of the oceans, nearer the continents.



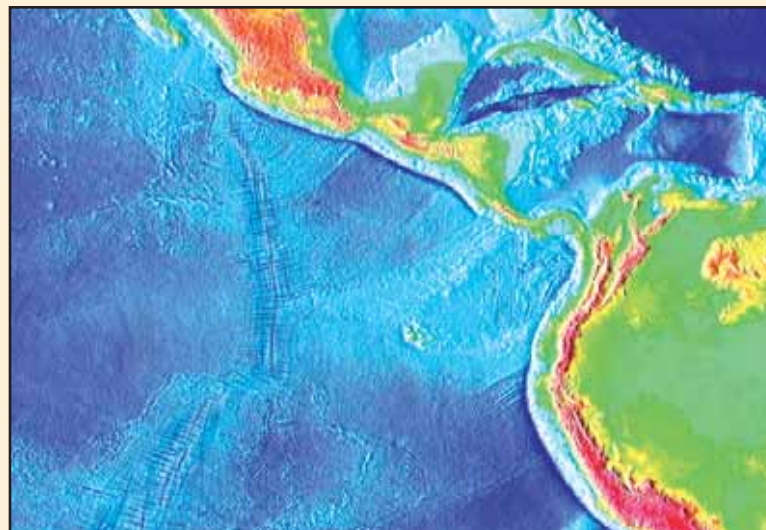




### Check Your Understanding

1. What is the difference between the lithosphere and the asthenosphere?
2. What does the abbreviation GPS stand for?
3. From where does a GPS receiver get its signal?
4. Why are GPS data not enough to confirm that the Earth's surface has been moving for many years?
5. What has caused the "zebra pattern" in the rock of the ocean floor?
6. What is the significance of the patterns of offsets along mid-ocean ridges?

not straight; it is offset in many places (*Figure 5*). The offsets are perpendicular to the axis of the ridge. When combined with knowledge that the ocean floor is spreading apart at mid-ocean ridges, geologists realized that the offsets are parallel to the direction the plates are moving. By mapping the orientations of these offsets, and entering this data into the computer model, the plate motion calculator is able to generate the directions of plate motions. Comparisons between GPS measurements and results from geologic computer models show very good agreement, within 4%.



**Figure 5** This map shows the network of fractures along the mid-ocean ridge in the eastern Pacific Ocean floor. Because the ocean floor spreads away from both sides of the ridge, the fractures indicate the direction of plate motion.

### Understanding and Applying What You Have Learned

1. Describe the direction and the rate of movement for the plate on which you live.
2. Examine the scale of the USGS topographic map of your community. Given the rate of plate motion in your community, estimate the minimum number of years that it would take for a change in the location of your school to be detected on a topographic map.

3. How does GPS provide evidence that the surface of the Earth moves over time?
4. Describe at least one advantage of using GPS technology to gather evidence of plate motion.
5. How do studies of the magnetism of rocks on the sea floor provide evidence that the surface of the Earth moves over time?
6. What evidence examined in this activity suggests that the direction and rate of motion of plates is not constant?
7. Look at the world map in the **Investigate** section showing the relative motion of plates. This map shows how plates move relative to each other.
  - a) Look at the names of the plates. On what basis does it appear that the plates were named?
  - b) Write down the name of your plate and all the plates that border it. Describe the motion of your plate relative to all the plates that border it.
  - c) How might the differences in motion of these plates affect the Earth's lithosphere?

## Preparing for the Chapter Challenge

In your notebook, write a paragraph to convince the middle-school students that your community is moving as part of the movement of a

much larger segment of the Earth's lithosphere. Describe the evidence used to make this determination.

## Inquiring Further

### 1. Technology used to detect plate motions

Explore how GPS allows plate movement to be measured. Excellent web sites that describe how GPS works can be found on the *EarthComm* web site.

### 2. Investigating scales of motion

Plate motion is extremely slow. Make a list of other things you know about (or have heard about) that move or take place slowly. Possible examples include growth

of fingernails, grass, tree height, tree-trunk diameter, and so on. Find out how fast they move. Compare the rate of these motions to the rate of movements of plates.

### 3. Study animations of plate motions

Visit the *EarthComm* web site for the address of animated images of the motions of lithospheric plates. Describe how the motions shown in the animations match your analysis from this activity.